CLAIMS

What is claimed is:

1. A fluidic nanotube, comprising:

a tubular member having first and second ends, and an inner bore between said first and second ends;

said tubular member having a non-porous inner wall;

said tubular member comprising a non-carbon, hydrophilic material;

wherein said nanotube is a functional component of a device selected from the group of devices consisting essentially of nanocapillary devices, field effect transistors, nanoelectrophoretic devices, detectors, DNA sequence detectors, immunosensors, tube-field-effect transistors, microfluidic wafers, nanocapillary wafers, electrode wafers, MEMS switching chips, transistors, sensors, thermoelectric devices, photonic devices, nanoelectromechanical actuators, nanoelectromechanical sensors, nanoscale fluidic bioseparators, and imaging devices.

2. A fluidic nanotube, comprising:

a tubular member having first and second ends, and an inner bore between said first and second ends;

said tubular member having a seamless inner wall;

said tubular member comprising a non-carbon, hydrophilic material;

wherein said nanotube is a functional component of a device selected from the group of devices consisting essentially of nanocapillary devices, field effect transistors, nanoelectrophoretic devices, detectors, DNA sequence detectors, immunosensors, tube-field-effect transistors, microfluidic wafers, nanocapillary wafers, electrode wafers, MEMS switching chips, transistors, sensors, thermoelectric devices, photonic devices, nanoelectromechanical actuators, nanoelectromechanical sensors, nanoscale fluidic bioseparators, and imaging devices.

3. A fluidic nanotube, comprising:

a tubular member having first and second ends, and an inner bore between

said first and second ends;

said tubular member having a non-porous inner wall;

said tubular member formed of a non-carbon-based material;

said tubular member comprising a hydrophilic material;

wherein said nanotube is a functional component of a device selected from the group of devices consisting essentially of nanocapillary devices, field effect transistors, nanoelectrophoretic devices, detectors, DNA sequence detectors, immunosensors, tube-field-effect transistors, microfluidic wafers, nanocapillary wafers, electrode wafers, MEMS switching chips, transistors, sensors, thermoelectric devices, photonic devices, nanoelectromechanical actuators, nanoelectromechanical sensors, nanoscale fluidic bioseparators, and imaging devices.

4. A fluidic nanotube, comprising:

a tubular member having first and second ends, and an inner bore between said first and second ends;

said tubular member having a seamless inner wall;

said tubular member formed of a non-carbon-based material;

said tubular member comprising a non-carbon, hydrophilic material;

wherein said nanotube is a functional component of a device selected from the group of devices consisting essentially of nanocapillary devices, field effect transistors, nanoelectrophoretic devices, detectors, DNA sequence detectors, immunosensors, tube-field-effect transistors, microfluidic wafers, nanocapillary wafers, electrode wafers, MEMS switching chips, transistors, sensors, thermoelectric devices, photonic devices, nanoelectromechanical actuators, nanoelectromechanical sensors, nanoscale fluidic bioseparators, and imaging devices.

5. A nanotube as recited in claim 1, 2, 3, or 4, wherein said nanotube is formed by the steps comprising:

forming a core material;

depositing a nanotube material over said core material; and

removing said core material.

6. A nanotube as recited in claim 5, wherein said core material is sacrificed during said removal step.

7. A nanotube as recited in claim 5, wherein said core material comprises a sacrificial template for said nanotube.

8. A nanotube as recited in claim 5:

wherein said core material has ends and a side surface; and

wherein said nanotube material is deposited on said side surface to form a cylindrical sheath through which said core material extends.

9. A nanotube as recited in claim 5, wherein said core material is single-crystalline.

10. A nanotube as recited in claim 5, wherein said nanotube material is single-crystalline.

11. A nanotube as recited in claim 5, wherein said core material comprises a material selected from the group of materials consisting essentially of zinc oxide (ZnO), silicon (Si), gallium nitride (GaN), germanium (Ge), silver (Ag), gold (Au), group II-VI materials, group III-V materials, elemental group IV materials, and metals.

12. A nanotube as recited in claim 11, wherein said nanotube material comprises a material selected from the group of materials consisting essentially of GaN, Si, GaAs, CdSe, GaP, InP, Ge, InAs, Group II, III, IV, V, and VI materials including quaternaries and tertiaries, as well as oxides, SiO, GaO, InO and other insulating materials, elemental metals, and polymers.

13. A nanotube as recited in claim 12, wherein the material selected for said nanotube material has a sufficiently similar crystalline structure and lattice constant as the material selected for said core material to allow epitaxial growth of

said nanotube material on said core material.

14. A nanotube as recited in claim 1, 2, 3 or 4, wherein said tubular member comprises a single longitudinal segment.

15. A nanotube as recited in claim 1, 2, 3 or 4, wherein said tubular member comprises multiple longitudinal segments.

16. A nanotube as recited in claim 1, 2, 3, or 4, wherein said nanotube is formed by the steps comprising:

forming a nanowire;

depositing at least one sheath of material over said nanowire; and

removing said nanowire;

wherein said remaining sheath material comprises said nanotube.

17. A nanotube as recited in claim 16, wherein said nanowire is sacrificed during said removal step.

18. A nanotube as recited in claim 16, wherein said nanowire comprises a sacrificial template for said nanotube.

19. A nanotube as recited in claim 16:

wherein said nanowire has ends and a side surface; and

wherein said sheath material is deposited on said side surface to form a cylindrical sheath through which said nanowire extends.

20. A nanotube as recited in claim 16, wherein said nanowire is single-crystalline.

21. A nanotube as recited in claim 16, wherein said sheath material is single-crystalline.

22. A nanotube as recited in claim 16, wherein said nanowire comprises a material selected from the group of materials consisting essentially of zinc oxide (ZnO), silicon (Si), gallium nitride (GaN), germanium (Ge), silver (Ag), gold (Au), group II-VI materials, group III-V materials, elemental group IV materials, and metals.

23. A nanotube as recited in claim 22, wherein said sheath material comprises a material selected from the group of materials consisting essentially of GaN, Si, GaAs, CdSe, GaP, InP, Ge, InAs, Group II, III, IV, V, and VI materials including quaternaries and tertiaries, as well as oxides, SiO, GaO, InO and other insulating materials, elemental metals, and polymers.

24. A nanotube as recited in claim 23, wherein the material selected for said sheath material has a sufficiently similar crystalline structure and lattice constant as the material selected for said nanowire material to allow epitaxial growth of said sheath material on said nanowire material.

25. A nanotube as recited in claim 1, 2, 3, or 4, wherein said nanotube is formed by the steps comprising:

forming a sacrificial nanowire template of zinc oxide (ZnO);

depositing at least one sheath of gallium nitride (GaN) over said nanowire; and

removing said nanowire;

wherein said sheath comprises a gallium nitride (GaN) nanotube structure.

26. A nanotube as recited in claim 25, wherein said nanowire comprises single-crystalline zinc oxide (ZnO).

27. A nanotube as recited in claim 25, wherein said gallium nitride (GaN) sheath is deposited over said nanowire by epitaxial casting.

28. A nanotube as recited in claim 27, wherein said epitaxial casting

comprises gallium nitride (GaN) chemical vapor deposition.

29. A method as recited in claim 28:

wherein trimethylgallium and ammonia are used as precursors to said chemical vapor deposition and is fed with argon or nitrogen carrier gas;

wherein said chemical vapor deposition of GaN is performed at approximately six hundred degrees Celsius (600 °C) to seven hundred degrees Celsius (700 °C).

30. A nanotube as recited in claim 25:

wherein said gallium nitride (GaN) nanotube has an inner diameter which is in the range from approximately thirty (30 nm) nanometers to two hundred (200 nm) nanometers;

wherein said gallium nitride (GaN) nanotube has a wall thickness which is in the range from approximately five ($5\,nm$) nanometers to fifty ($50\,nm$) nanometers.

31. A nanotube as recited in claim 25, wherein said nanowire of zinc oxide (ZnO) is removed by subjecting it to elevated temperature in an atmosphere containing hydrogen gas.

32. A nanotube as recited in claim 31:

wherein said elevated temperature comprises approximately six hundred degrees Celsius (600 °C);

wherein said atmosphere comprises approximately ten percent (10%) hydrogen gas in an argon gas atmosphere.

33. A nanotube as recited in claim 25, wherein said nanowire of zinc oxide (ZnO) is removed by subjecting said array to chemical etching.

34. A nanotube as recited in claim 33, wherein said chemical etching comprises ammonia etching at sufficiently elevated temperature for removal of said zinc oxide nanowire.

35. A nanotube as recited in claim 1, 2, 3, or 4, wherein said nanotube is formed by the steps comprising:

forming a core material;

oxidizing said core material to form a sheath comprising an oxide of said core material; and

removing said core material.

36. A nanotube as recited in claim 35, wherein an oxide cap on the ends of said core material is removed prior to removing said core material.

37. A nanotube as recited in claim 35, wherein said core material is sacrificed during said removal step.

38. A nanotube as recited in claim 35, wherein said core material comprises a sacrificial template for said nanotube.

39. A nanotube as recited in claim 35, wherein said core material is single-crystalline.

40. A nanotube as recited in claim 35, wherein said sheath is single-crystalline.

41. A nanotube as recited in claim 35, wherein said core material comprises a material selected from the group of materials consisting essentially of zinc oxide (ZnO), silicon (Si), gallium nitride (GaN), germanium (Ge), silver (Ag), gold (Au), group II-VI materials, group III-V materials, elemental group IV materials, and metals.

42. A nanotube as recited in claim 41, wherein said sheath comprises a material selected from the group of materials consisting essentially of GaN, Si, GaAs, CdSe, GaP, InP, Ge, InAs, Group II, III, IV, V, and VI materials including

quaternaries and tertiaries, as well as oxides, SiO, GaO, InO and other insulating materials, elemental metals, and polymers.

43. A nanotube as recited in claim 42, wherein the material selected for said sheath material has a sufficiently similar crystalline structure and lattice constant as the material selected for said core material to allow epitaxial growth of said sheath on said core material.

44. A nanotube as recited in claim 1, 2, 3 or 4, wherein said nanotube is formed by the steps comprising:

forming a sacrificial nanowire template of a first material;

forming a sheath of modified said first material over said nanowire; and

removing said nanowire;

wherein said sheath is a nanotube structure.

45. A nanotube as recited in claim 44, wherein said nanowire comprises a single-crystalline material.

46. A nanotube as recited in claim 44, wherein said sheath is formed on said nanowire by thermal oxidation.

47. A nanotube as recited in claim 44, wherein said nanowire is removed in an etching process.

48. A nanotube as recited in claim 44:

wherein said first material comprises silicon (Si);

wherein said modified first material comprises silicon oxide (SiO_2).

49. A nanotube as recited in claim 48, wherein said sheath is formed on said nanowire by a thermal oxidation process in which temperature determines the thickness of said sheath.

50. A nanotube as recited in claim 49, wherein the temperature of said thermal oxidation is in the range of from approximately eight hundred degrees Celsius (800 °C) to approximately one thousand degrees Celsius (1000 °C).

51. A nanotube as recited in claim 49, wherein said nanowire is removed in an etching process comprising:

covering the combination of said sheath and nanowire with an etch-resistant material;

removing the top end of the sheathed nanowire while the sheathed walls of said nanotube are protected by said etch-resistant material;

removing the silicon (Si) nanowire material from within said silicone oxide (SiO_2) nanotube; and

removing said etch-resistant material.

52. A nanotube as recited in claim 51, wherein said etch-resistant material comprises a dimer or polymer.

53. A nanotube as recited in claim 52, wherein said etch-resistant material comprises perylene.

54. A nanotube as recited in claim 53, wherein said removing the top end of said sheathed nanowire comprises:

etching in oxygen plasma to remove sufficient depth of said etch-resistant material to expose said sheathed nanowires; and

etching in hydrofluoric acid to remove the metal cap of said nanowire.

55. A nanotube as recited in claim 54, wherein said removal of the silicon (Si) nanowire comprises etching in xenon fluorine (XeF2).

56. A nanotube as recited in claim 51, wherein removal of said etch resistant material comprises oxygen plasma etching.

57. A tubular field effect transistor (TFET), comprising:

at least one semiconducting nanotube;

a reservoir fluidly coupled to each end of said nanotube;

a source electrode attached to a first end of said nanotube; and

a drain electrode attached to a second end of said nanotube;

wherein the passage of molecular species through said nanotube changes source to drain current flow.

58. A transistor as recited in claim 57, further comprising capture molecules retained within said nanotube for capturing or slowing select molecular species.

59. A transistor as recited in claim 57, further comprising a gate electrode attached toward the center of said nanotube for controlling ion transport through said nanotube.

60. A transistor as recited in claim 57, wherein said tubular field effect transistor is a functional component of a device selected from the group of devices consisting essentially of nanocapillary devices, field effect transistors, nanoelectrophoretic devices, detectors, DNA sequence detectors, immunosensors, tube-field-effect transistors, sensors, thermoelectric devices, photonic devices, nanoelectromechanical actuators, nanoelectromechanical sensors, nanoscale fluidic bioseparators, and imaging devices.

61. A tubular field effect transistor (TFET), comprising:

at least one semiconducting nanotube;

a reservoir fluidly coupled to each end of said nanotube;

a source electrode coupled proximal a first end of said nanotube;

a drain electrode coupled proximal a second end of said nanotube; and

capture molecules retained within said nanotube for capturing or slowing select molecular species;

wherein the passage of molecular species through said nanotube changes source to drain current flow.

62. A transistor as recited in claim 61, further comprising a gate electrode coupled toward the center of said semiconducting nanotube for controlling ion transport through said nanotube.

63. A transistor as recited in claim 61, wherein said tubular field effect transistor is a functional component of a device selected from the group of devices consisting essentially of nanocapillary devices, field effect transistors, detectors, DNA sequence detectors, immunosensors, tube-field-effect transistors, sensors, thermoelectric devices, photonic devices, nanoelectromechanical actuators, nanoelectromechanical sensors, nanoscale fluidic bioseparators, and imaging devices.

64. A tubular field effect transistor (TFET), comprising:

at least one semiconducting nanotube;

a reservoir fluidly coupled to each end of said nanotube;

a source electrode coupled proximal a first end of said nanotube;

a drain electrode coupled proximal a second end of said nanotube; and

a gate electrode coupled toward the center of said nanotube for controlling ion transport through said nanotube;

wherein the passage of molecular species through said nanotube changes source to drain current flow.

65. A transistor as recited in claim 64, further comprising capture molecules retained within said nanotube for capturing or slowing select molecular species.

66. A transistor as recited in claim 64, wherein said tubular field effect transistor is a functional component of a device selected from the group of devices

consisting essentially of nanocapillary devices, field effect transistors, detectors, DNA sequence detectors, immunosensors, tube-field-effect transistors, sensors, thermoelectric devices, photonic devices, nanoelectromechanical actuators, nanoelectromechanical sensors, nanoscale fluidic bioseparators, and imaging devices.

67. A tubular field effect transistor (TFET), comprising:

at least one semiconducting nanotube;

a reservoir fluidly coupled to each end of said nanotube;

a source electrode coupled proximal a first end of said nanotube;

a drain electrode coupled proximal a second end of said nanotube;

a gate electrode coupled toward the center of said nanotube for controlling ion transport through said nanotube; and

capture molecules retained within said nanotube for capturing or slowing select molecular species;

wherein the passage of molecular species through said nanotube changes source to drain current flow.

68. A transistor as recited in claim 67, wherein said tubular field effect transistor is a functional component of a device selected from the group of devices consisting essentially of nanocapillary devices, field effect transistors, detectors, DNA sequence detectors, immunosensors, tube-field-effect transistors, sensors, thermoelectric devices, photonic devices, nanoelectromechanical actuators, nanoelectromechanical sensors, nanoscale fluidic bioseparators, and imaging devices.

69. A nanocapillary electrophoresis device, comprising:

at least one hydrophilic nanotube;

a plurality of capture molecules retained within said nanotube for capturing or slowing selected molecular species;

a reservoir fluidly coupled to each end of said nanotube;

a source electrode coupled proximal a first end of said nanotube; and

a drain electrode coupled proximal a second end of said nanotube;

wherein the passage of molecular species through said nanotube changes ionic current flow.

70. A device as recited in claim 69, further comprising:

an optical single-molecule detection and identification system configured for generating an optical detection signal in response to molecules passing through said nanotube; and

a coincidence circuit configured to generate coincident molecule detection signal in response to the coincidence between said ionic current flow and said optical detection signal;

whereby the use of coincident detection increases false positive immunity.

71. A device as recited in claim 69, wherein said electrophoretic device is a functional component of a device selected from the group of devices consisting essentially of nanocapillary devices, nanoelectrophoretic devices, detectors, DNA sequence detectors, immunosensors, sensors, thermoelectric devices, photonic devices, nanoelectromechanical actuators, nanoelectromechanical sensors, nanoscale fluidic bioseparators, and imaging devices.

72. A nanocapillary electrophoresis array technology (NEAT) device, comprising:

a hydrophilic nanotube;

a plurality of capture molecules retained within said nanotube for capturing or slowing selected molecular species;

a reservoir fluidly coupled to each end of said nanotube;

a source electrode coupled proximal a first end of said nanotube;

a drain electrode coupled proximal a second end of said nanotube;

wherein the passage of molecular species through said nanotube changes ionic current flow;

wherein the above structures comprise an electrophoresis cell;

an array of said electrophoresis cells; and

means for detecting the current from each of said electrophoresis cells.

73. A device as recited in claim 71, wherein said electrophoretic device is a functional component of a device selected from the group of devices consisting essentially of nanocapillary devices, nanoelectrophoretic devices, detectors, DNA sequence detectors, immunosensors, sensors, thermoelectric devices, photonic devices, nanoelectromechanical actuators, nanoelectromechanical sensors, nanoscale fluidic bioseparators, and imaging devices.

74. A device as recited in claim 71, wherein said detecting means comprises:

a plurality of switching elements configured for selecting one or more of the electrophoresis cells in said array; and

a circuit for conditioning the signals received from each said electrophoresis cell.

75. A device as recited in claim 74, wherein said plurality of switching elements have a row and column arrangement for accessing cells within a two-dimensional array of said electrophoresis cells.

76. A device as recited in claim 74, wherein said switching elements have an off-state leakage current which is less than approximately 5 pA per 1 μm of gate length for $V_{ds} \approx 2.2$ Volts.

77. A device as recited in claim 76, wherein each of said switching elements comprises a micro-electromechanical systems (MEMs) switch using switch contacts which are separated by an air-gap in the off-state and bridge the air-gap to establish a connection when in the on-state.

78. A device as recited in claim 77, wherein said MEMs switching elements comprises:

multiple signal contacts;

an activation contact; and

a flexible conductive beam configured for deflection toward said activation contact in response to an activation voltage potential, wherein during said deflection said flexible conductive beams makes contact with said multiple signal contacts establishing a conduction path between the multiple signal contacts.

79. A device as recited in claim 78, further comprising insulation disposed between said activation contact and said flexible conductive beam so that a conduction path is not established between said activation contact and said flexible conductive beam in response to deflection of said flexible conductive beam.

80. A semiconductor device, comprising:

a nanotube formed from a plurality of sheaths of alternatively doped semiconductor material; and

a plurality of electrical contacts coupled to said alternatively doped sheaths for establishing electrical connection to said device.

81. A semiconductor device as recited in claim 80, wherein said semiconductor device is selected from the group of semiconductor devices consisting essentially of diodes, light emitters, light detectors, electron transport devices, bipolar transistors, FETs, insulated gate FETs, and combinations thereof.

82. A semiconductor device as recited in claim 80, wherein said alternatively doped sheaths are doped with different doping species and/or at different doping levels.

83. A semiconductor device as recited in claim 80, wherein at least two of said sheaths form a p-n or n-p junction.

84. A semiconductor device as recited in claim 80, wherein said sheaths form a p-n-p or n-p-n junction.

85. A semiconductor device as recited in claim 80, further comprising an insulating sheath between at least two of said sheaths of alternatively doped semiconductor material.

86. A semiconductor device as recited in claim 85, wherein at least two of said sheaths form a p-i, i-p, n-i, or i-n junction.

87. A semiconductor device as recited in claim 85, wherein said sheaths form a p-i-n, n-i-p, n-i-n, or p-i-p junction.

88. A semiconductor device as recited in claim 80, wherein said sheaths of semiconductor material are formed about a nanowire core which is later removed.

89. A semiconductor device as recited in claim 80, wherein at least one said electrical contact is within the core of said sheaths.

90. A semiconductor device, comprising:

a nanotube formed from a plurality of longitudinal segments of alternatively doped semiconductor material; and

a plurality of electrical contacts coupled to said alternatively doped longitudinal segments for establishing electrical connection to said device.

91. A semiconductor device as recited in claim 90, wherein said semiconductor device is selected from the group of semiconductor devices consisting essentially of diodes, light emitters, light detectors, electron transport devices, bipolar transistors, FETs, insulated gate FETs, and combinations thereof.

92. A semiconductor device as recited in claim 80, wherein said

alternatively doped longitudinal segments are doped with different doping species and/or at different doping levels.

93. A semiconductor device as recited in claim 90, wherein at least two of said longitudinal segments form a p-n or n-p junction.

94. A semiconductor device as recited in claim 90, wherein said longitudinal segments form a p-n-p or n-p-n junction.

95. A semiconductor device as recited in claim 90, further comprising an insulating segment between at least two said longitudinal segments of alternatively doped semiconductor material.

96. A semiconductor device as recited in claim 95, wherein at least two of said longitudinal segments form a p-i, i-p, n-i, or i-n junction.

97. A semiconductor device as recited in claim 95, wherein said longitudinal segments form a p-i-n, n-i-p, n-i-n, or p-i-p junction.

98. A semiconductor device as recited in claim 90, wherein said longitudinal segments of semiconductor material are formed about a nanowire core which is later removed.

99. A semiconductor device as recited in claim 90, wherein at least one said electrical contact is within the core of said longitudinal segments.

100. A semiconductor device, comprising:

a nanotube formed from a plurality of longitudinal segments and sheaths of alternatively doped semiconductor material; and

a plurality of electrical contacts coupled to said alternatively doped longitudinal segments and/or sheaths for establishing electrical connection to said

device.

101. A semiconductor device as recited in claim 100, wherein said semiconductor device is selected from the group of semiconductor devices consisting essentially of diodes, light emitters, light detectors, electron transport devices, bipolar transistors, FETs, insulated gate FETs, and combinations thereof.

102. A semiconductor device as recited in claim 100, wherein said alternatively doped longitudinal segments and sheaths are doped with different doping species and/or at different doping levels.

103. A semiconductor device as recited in claim 100, wherein at least two alternatively doped of said longitudinal segments and/or sheaths form a p-n or n-p junction.

104. A semiconductor device as recited in claim 100, wherein at said alternatively doped of said longitudinal segments and/or sheaths form a p-n-p or n-p-n junction.

105. A semiconductor device as recited in claim 100, further comprising an insulating segment or sheath between at least two said longitudinal segments and/or sheaths of alternatively doped semiconductor material.

106. A semiconductor device as recited in claim 105, wherein at least two of alternatively doped of said longitudinal segments and/or sheaths form a p-i, i-p, n-i, or i-n junction.

107. A semiconductor device as recited in claim 105, wherein alternatively doped of said longitudinal segments and/or sheaths form a p-i-n, n-i-p, n-i-n, or p-i-p junction.

108. A semiconductor device as recited in claim 100, wherein said longitudinal segments and sheaths of semiconductor material are formed about a nanowire core which is later removed.

109. A semiconductor device as recited in claim 100, wherein at least one said electrical contact is within the core of said longitudinal segments.